

# Optimization of alternate profile component part machining

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**Abstract.** Process optimization for machining of component parts with the profile alternate by the length has been reviewed here. The review deals with the optimization criteria applied and shows that the optimization of machining modes normally uses a criterion of cost-effectiveness, which is most often used in up-to-date technologies. With reference to specific organizational and economic conditions at companies of the industry, it is shown that power saving may become a priority when standardizing modes of machining. The power consumption pattern for the cutting process is reviewed. A variable energy value is proposed as an optimality criterion, which depends on parameters optimized i.e. – technological energy. Mathematical models are defined for the optimality criterion and limiting parameters that allow reducing energy consumption of the machining process. Calculations carried out according to the proposed methodology have shown that when the machine electric motor power is above 13.5 kW, work in the energy-saving mode becomes economically viable. Energy savings reach 10 %, while the main time increases by an average of 10%, but the reduction in costs associated with a decrease in energy consumption is 4 times higher than the increase in costs due to an increase in the main time.

## 1. Introduction

In present time, a machine-building enterprise can do well only if its manufacturing process is optimal. Therefore, the issue of process optimization is one of the most important [1–5].

When optimizing machining modes, a criterion of cost efficiency is normally used being a favorite criterion in up-to-date technologies [5–10]. However, energy saving may become a priority of optimizing calculations with reference to specific organizational and economic conditions at companies of the industry, when standardizing modes of machining. To create cutting mode calculation algorithms, it is necessary to review and formalize the criterion structure including that considering specific features of machining of housings.

## 2. Methods

In its most general form, the goal function

$$E = N\tau_m \rightarrow \min$$

where  $E$  is the power put in the machine during  $\tau_m$ ,  $N$  is the capacity put out by the machine motors,  $\tau_m$  is the machining time.

The power consumed by the machine can be represented as the sum of the energies

$$E = E_c + E_w + E_t + E_s + E_l + E_f + E_{fr} + E_r$$



The equation indicates the energies used for:  $E_c$  – cutting,  $E_w$  – workpiece clamping,  $E_t$  – fast feed and removal of toolheads,  $E_s$  – running of electric and electronic control systems,  $E_l$  – machine workspace lighting,  $E_f$  – cutting fluid feeding to the machine workspace,  $E_{fr}$  – friction in the mechanisms and units of the machine,  $E_r$  – circuit resistance.

The cutting energy  $E_c$  is the largest component of  $E$ . The other terms can be combined into two groups:  $E_1$  is the energy component related directly to the main time  $\tau_o$ , и  $E_2$  is the energy component, which is a constant of the specific operation, so it can be written

$$E = E_c + E_1 + E_2,$$

where

$$E_1 = E_w + E_f + E_{fr} + E_r = (N_w + N_f + N_{fr} + N_r)\tau_o,$$

$$E_2 = E_t + E_s + E_l$$

$E_2$  is a constant value and can be excluded from the optimization system for this operation. We introduce the value of technological energy  $E_o$  as the optimality criterion

$$E_o = E_c + E_1 \Rightarrow \min$$

To determine the cutting energy value  $E_c$ , it is necessary to determine the cutting power  $N_c$ . Entering the correspondence

$$N_c = C_1 P_z V$$

The component of the cutting force  $P_z$  is determined by the equation

$$P_z = C_2 V^x S^y t^z$$

The main time  $\tau_o$  can be found using the equation

$$\tau_o = C_3 V^{-1} S^{-1}$$

Then

$$E_c = C_4 V^x S^{y-1} t^z$$

or through the machine spindle rotation speed

$$E_c = C_5 n^x S^{y-1} t^z.$$

When processing alternate profile surfaces with several tools, the following parameters are metered at each  $i^{th}$  turn of the workpiece: the cutting speed  $V$ , the workpiece rotation speed  $n$ , the feed  $S$ , the cutting depth  $t$  for each tool  $k$ . If over the time  $\tau_o$  the number of workpiece turns is  $A$ , then  $E_p$  can be calculated by the equation

$$E_c = C_5 \sum_{i=1}^A \sum_{j=1}^k n_{ji}^x S_{ji}^{y-1} t_{ji}^z,$$

Where  $n_{ji}$ ,  $S_{ji}$ ,  $t_{ji}$  are spindle speed, feed and cutting depth for the  $j^{th}$  tool at the moment of the  $i^{th}$  workpiece turn determined by the method.

The optimization system has to be modified with limitations for motor capacity, spindle torque, machined face coarseness, throughput and kinematics of the machine.

For multi tool machining

$$N_c = \sum_{j=1}^k N_{pi} = C_6 n_i^x \sum_{j=1}^k S_{ij}^{y-1} t_{ij}^z$$

Spindle torque

$$M_{St} = \sum_{j=1}^k M_{Sji} = 0.5 C_7 n_i^x \sum_{j=1}^k D_{ji} S_{ij}^{y-1} t_{ij}^z,$$

where  $M_{Sji}$  is a torque created by the cutting force of the  $j^{\text{th}}$  tool at the  $i^{\text{th}}$  turn of the workpiece.

Since the feed values may vary, the resulting coarseness of the treated surface  $R_z$  has to be calculated and compared to the coarseness  $R_{za}$  allowed by the component drawing.

In mass and large-scale production, the throughput depends highly on the main time  $\tau_o$ . Therefore, the throughput limit can be defined by the following correspondence

$$\tau_o \leq \tau_{\max},$$

where  $\tau_o$  is calculated machining time,  $\tau_{\max}$  is maximum allowed machining time.

When the operation uses  $k$  tools, for the  $j^{\text{th}}$  tool, if the conditions are met  $n = \text{const}$ ,  $S = \text{const}$

$$\tau_{oj} = C_8 n^{-1} S_j^{-1}$$

There are a few ways to distribute using of the tools over time and, accordingly, equations of the limit by  $\tau_o$ . We should consider the main of them.

When all number of  $k$  tools work at the same time, the limit is the base time  $\tau_{oj}$  of the one that has it at maximum

$$(C_8 n^{-1} S^{-1})_{\max} \leq \tau_{\max}$$

When all number of  $k$  tools work one by one, then

$$n^{-1} \sum_{j=1}^k (C_8 S_j^{-1}) \leq \tau_{\max}.$$

When the tools work one by one in groups having numbers  $(1, \dots, u, \dots, w)$ , then inside each  $u^{\text{th}}$  group there is  $u_j^{\text{th}}$  tool, for which  $\tau_{ouj}$  is maximum allowed as compared to others within the group.

Then

$$n^{-1} \sum_{u=1}^w (C_8 u_j S_{uj}^{-1})_{\max} \leq \tau_{\max}$$

Thus, if a component machined has a complex surface profile consisting of  $A$  elementary sections at the same time  $k$ , we obtain an optimization system in the following form.

Target function

$$C_5 \sum_{i=1}^A \sum_{j=1}^k n_i^x S_{ij}^{y-1} t_{ij}^z + (N_w + N_{fr} + N_f + N_r) \tau_o \rightarrow \min$$

Limitations:

- by motor power

$$C_6 n_i^x \sum_{j=1}^k S_{ji}^{y-1} t_{ji}^z \leq N_{mp},$$

- by spindle torque

$$0.5C_7n_i^x \sum_{j=1}^k D_{ji}S_{ji}^{y-1} \bar{t}_{ji} \leq M_{st},$$

- by coarseness of the surface machined

$$\frac{10^3 S_{ji}^2}{8r_j} \leq R_{z_{sm}},$$

- by base time

$$\tau_{\max} \leq \tau_{ob},$$

- by machine's kinematics

$$n_{m \min} \leq n_i \leq n_{m \max}, S_{m \min j} \leq S_{ij} \leq S_{m \max j}$$

### 3. Conclusion

Calculated by the method proposed, the calculations show that working in the power-saving mode is cost-effective when the machine's motor has a capacity higher than 13.5 kW. Power savings reaches 10 %, while the main time increases by 10 % at average, but the cost saving due to reduced power consumption is 4 times higher than the cost rise due to the main time increased.

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